

# Flaring variability of Microquasars

Sergei A. Trushkin, Nikolaj N. Bursov, Nikolaj A. Nizhelskij

*Special Astrophysical Observatory RAS, Nizhnij Arkhyz, 369167, Russia*

**Abstract.** We discuss flaring variability of radio emission of microquasars, measured in monitoring programs with the RATAN-600 radio telescope. We carried out a multi-frequency (1-30 GHz) daily monitoring of the radio flux variability of the microquasars SS433, GRS1915+105, and Cyg X-3 during the recent sets in 2005-2007. A lot of bright short-time flares were detected from GRS 1915+105 and they could be associated with active X-ray events. In January 2006 we detected a drop down of the quiescent fluxes from Cyg X-3 (from 100 to  $\sim 20$  mJy), then the 1 Jy-flare was detected on 2 February 2006 after 18 days of quenched radio emission. The daily spectra of the flare in the maximum were flat from 2 to 110 GHz, using the quasi-simultaneous observations at 110 GHz with the RT45m telescope and the NMA millimeter array of NRO in Japan. Several bright radio flaring events (1-15 Jy) followed during the continuing state of very variable and intensive 1-12 keV X-ray emission ( $\sim 0.5$  Crab), which was monitored in the RXTE ASM program. Swift/BAT ASM hard X-ray fluxes correlated strongly with flaring radio data. The various spectral and temporal characteristics of the light curves from the microquasars could be determined from such comparison. We conclude that monitoring of the flaring radio emission is a good tracer of jet activity X-ray binaries.

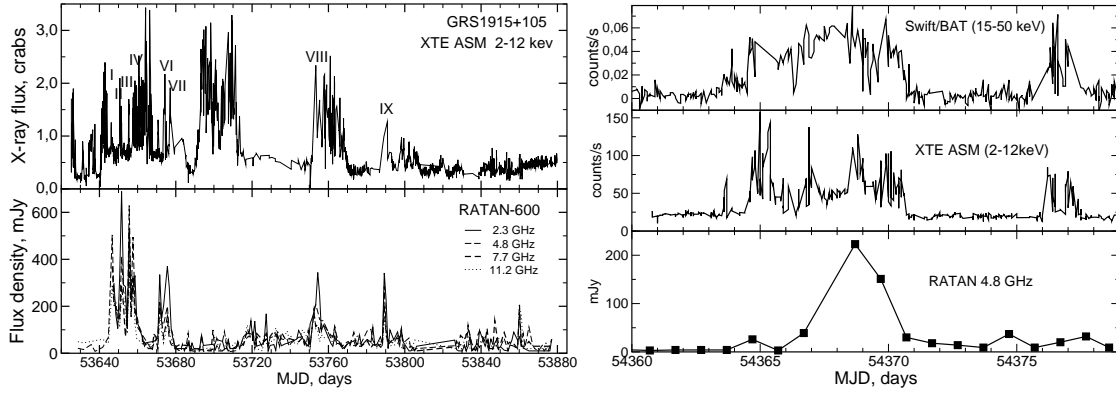
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## Introduction

The first idea about cosmic radio sources variability belongs to Shklovskij, who predicted the secular decreasing of the total radio flux from the SNR Cas A [1]. Strong variability of the cosmic sources was detected from extragalactic sources, quasars and AGNs in 60th years, and later from SS433, prototype radio emitted X-ray binary with merely relativistic jets. Van der Laan developed Shklovskij's idea to generalize the main formulae and showed that any synchrotron emitting source should evolve in a similar manner [2]. Marscher and Gear [3] were the first who to use Rees's idea [4] about internal shocks, running in the jets of flaring quasar 3C273.

Variable synchrotron emission in microquasars, quasars and AGNs is originated from outflows of accreting matter in the narrow cone – the two-side relativistic jets, ejected from polar regions of accretion disks around black holes or neutron stars. The jets contain magnetic fields and energetic electrons. The temporal and frequency dependencies in the light curves are a key for clear understanding and good probe test for models of the physical processes in cosmic jets. A comparison of the radio and X-ray variable emission allows us to provide detailed studies.



**FIGURE 1.** Light curves of GRS1915+105 at radio frequencies and at 2-12 keV from September 2005 to March 2006 and light curves of GRS1915+105 at radio frequencies and X-ray 2-12 keV and 15-50 keV fluxes in September 2007.

## Observations

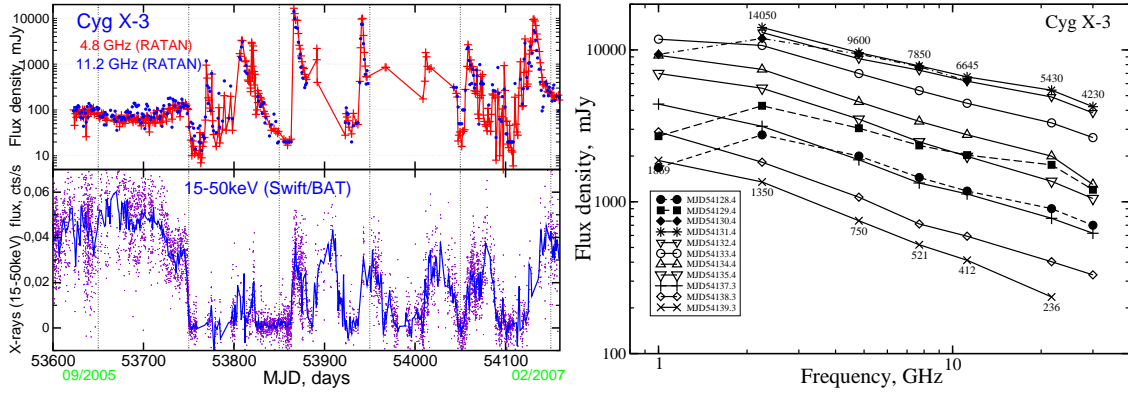
We have carried out the almost daily monitoring observational sets of the micro-quasars Cyg X-3, GRS 1915+10, SS433 from September 2005 to May 2006, in July 2006, from November 2006 to March 2007 and from December 2007 to February 2008 at frequencies from 1 to 30 GHz. The measured multi-frequency light curves can be directly compared with time series of the X-ray observatory RXTE [5] and hard X-ray data from Swift/BAT (15-50 keV)[6]. The observations have been made with the ‘Northern sector’ antenna of the RATAN-600 radio telescope in a transit mode. As a rule the errors of measured fluxes of the sources did not exceed 5-10 per cent. The details of the observations, the errors are given in [7].

## GRS 1915+105: X-ray – radio correlation

The X-ray transient source GRS 1915+105 was discovered in 1992 by Castro-Tirado et al. [8] with the WATCH instrument on board GRANAT. An apparent super-luminous motion of the jet components was detected and the determination of ‘microquasars’ were coined [9]. Fender et al. [10] discussed the alert observations of two flares (July 2000), when for the first time detected the quasi-periodical oscillations with  $P = 30.87$  minutes at two frequencies: 4.8 and 8.64 GHz. Linear polarization was measured at a level 1-2 per cent at both frequencies as well.

In Fig.1(left) the radio and X-ray light curves are showed for the total set of 2005-2006. The nine radio flares have the counterparts in X-rays. The radio spectrum was optically thin in the first two flares, and optically thick in the third one (see details in [11]). In Fig.1 (right) the radio and soft and hard X-ray light curves during the September-October 2007. Again we see detectable correlation between the radio flare and a soft X-ray ‘spike’ in the high state.

The profiles of the X-ray spikes during the radio flares are clearly distinguishable from other spikes because its shape shows a fast-rise and a exponential-decay. The X-



**FIGURE 2.** (right) The RATAN and Swift/BAT light curves of Cyg X-3 from September 2005 to February 2007 and (left): The daily spectra of Cyg X-3 during the flare in Jan-Feb 2007.

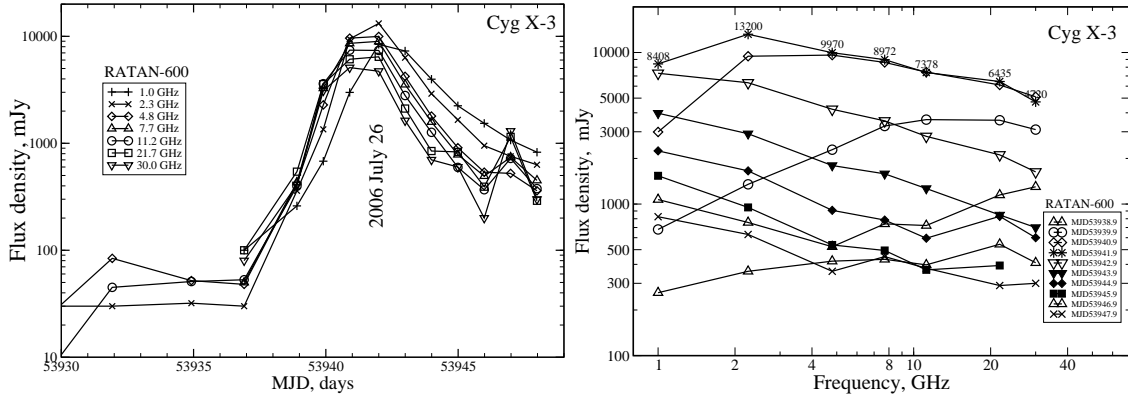
ray spikes, which reflect activity of the accretion disk, show an irregular pattern. During a bright radio flare, the spectra of the X-ray spikes become softer than those of the quiescent phase, by a fraction of  $\sim 30\%$  [11]. But such rule is not universal.

Miller et al. [12] have detected a one-side large-scale radio jet from GRS1915+105 with VLBA mapping during an X-ray and (IX) radio outburst on 23 February 2006 (MJD53789.258). Then the optically thin flare with fluxes 340, 340, 342, 285, 206, and 153 mJy was detected at frequencies 1, 2.3, 4.8, 7.7, 11.2 and 21.7 GHz respectively.

### Cyg X-3: 2006-2007 – a new long-term active period

During 100 days (September – December 2005) Cyg X-3 was in a quiescent state of  $\sim 100$  mJy (Fig.2). In December 2005 its X-ray flux began to increase and the radio flux at 2-11 GHz increased also. Then the flux density of the source at 4.8 GHz was found to drop from 103 mJy on 2006 Jan 14.4 (UT) to 43 mJy on Jan 15.4 (UT), and to 22 mJy on Jan 17.4 (UT). The source is known to exhibit radio flares typically with a few peaks exceeding 1-5 Jy following such a quenched state as Waltman et al. [13] have showed in the intensive monitoring of Cyg X-3 with the Green Bank Interferometer at 2.25 and 8.3 GHz. The source has been monitored from 2006 Jan 25 (UT) with the Nobeyama Radio Observatory 45m Telescope (NRO45m Telescope), the Nobeyama Millimeter Array (NMA) and Japanese VLBI Network telescopes. On Feb 2.2 (UT), about 18 days after it entered the quenched state, the rise of a first peak is detected with the NRO45m Telescope and YRT32m. On Feb 3.2 (UT), the flux densities reached the first peak at all the sampling frequencies from 2.25 GHz to 110.10 GHz ([14]). The spectrum at maximum (3 February) of the flare was flat as measured by RATAN, NRO RT45m and NMA from 2 to 110 GHz. The next peak of the active events on 10 February reached the level of near 1 Jy again with a similar flat spectrum. Then three short-time flares have happened during a week. The flare on 18 February had the inverted spectrum with the same spectral index  $\alpha = +0.75$  from 2.3 to 22 GHz.

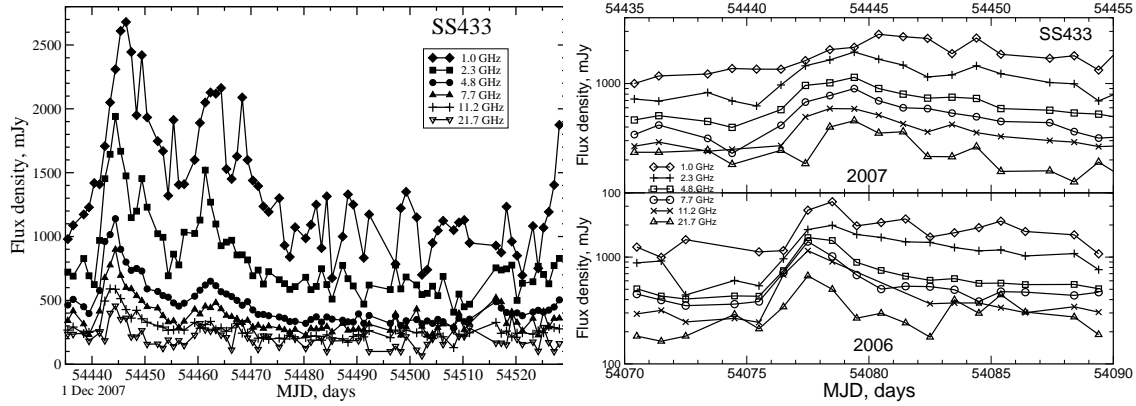
In the active period (2006) there were two powerful flares, March 14 to 3-5 Jy and



**FIGURE 3.** The RATAN and RXTE ASM light curves of Cyg X-3 in July 2006 (right) and the daily spectra of Cyg X-3 during flare in July 2006 (left).

May 11 to 12-16 Jy at 2-30 GHz. In the May flare fluxes have grown up by a factor  $\sim 1000$  during a day. The change of the spectrum during the flare on May 11-19 followed the model of a single ejection of the relativistic electrons, moving in thermal matter in the intensive WR-star wind. It stays in optically thin mode at higher frequencies, meanwhile at lower frequency 614 MHz [15] Cyg X-3 was in hard absorption. In the continuing active state of Cyg X-3 we detected a very fast-rise flare at 2.3 and 8.5 GHz with RT32 (IAA) on 5 June 2006 (MJD53891) [16]. During 3 hours the fluxes changed from  $\sim 1$  Jy to 2 Jy and then decreased to 100-400 mJy during 15 hours. We detected the similar behaviour in the the Jan-Feb 2007, when maximum flux reached 14 Jy at 2.3 GHz (Fig:2).

In Fig.3 the light curves of the July flare are shown. The phase of the flux rising continued during 4-5 days. For the first time we could clearly see the evolution of the spectrum during the phase of the flare (Fig.3). And it was amazing that the low-frequency part of the spectra evolved from nearly flat optically thin (at 1 GHz) on the first day to optically thick after 3-4 days. In the standard model of the expansion of the compact sources (jets components) there is no any explanation for such behaviour. We had to conclude that the thermal electron density, responsible for the low frequency absorption, grows up during grow-up of the relativistic electron density. The later stage of the spectral and temporal evolution could be fitted by the modified finite segments model by Marti et al. [17] or Hjellming [18] and Hjellming et al. [19]. Indeed in Fig.3 the radio spectra of the July flare evolved from the fourth day (MJD53942) as usual adiabatically expanding relativistic jets moving with  $v_{jet} \sim 0.74c$ , and thermal electron component has:  $T_e = 10^4$  K,  $n_{th} = 2 \cdot 10^4 \text{ cm}^{-3}$ , magnetic field  $B_0 = 0.07$  Gs, and energy index  $\gamma = -1.85$ . During the rising stage of the flare we should involve the intense internal shocks running through the jet [20].



**FIGURE 4.** The light curves of SS433 in December 2007 - January 2008 during the powerful flaring events, and comparison two flare in December 2006 and December 2007

### *SS433: new flaring events and their spectra*

The first microquasar SS433, a bright variable emission star was identified with a rather bright compact radio source 1909+048 located in the center of a supernova remnant W50. In 1979 moving optical emission lines, Doppler-shifted due to precessing mass outflows with 78000 km/s, were discovered in the spectrum of SS433. At the same time in 1979 were discovered a unresolved compact core and 1 arcsec long aligned jets in the MERLIN radio image of SS433. Since 1979 many monitoring sets (for ex., with GBI [21], RATAN [22]) were began. Different data do indicate a presence of a very narrow (about  $1^\circ$ ) collimated beam at least in X-ray and optical ranges. At present there is no doubt that SS433 is related to W50. A distance of near 5 kpc was later determined by different ways including the direct measurement of proper motions of the jet radio components.

Kotani et al. [23] detected the fast variation in the X-ray emission of SS433 during the radio flares, and probably QPOs of 0.11 Hz. Massive ejections during this active period could be the reason of such behavior. The daily RATAN light curves are measured from September 2005 to May 2006. The activity of SS433 began during the second half of the monitoring set. Some flares happened just before and after the multi-band program of the studies of SS433 in April 2006 [24].

In Fig.4(left) the light curves during the bright flare in December 2007 are showed. The delay of the maximum flux at 1 GHz is about 2 days and 1 day at 2.3 GHz relative to the maxima at higher frequencies.

In Fig.4(right) the light curves during the bright flares in December 2006 and 2007 are showed. The surprising coincident dates (6-7 Dec) of both flares could be evidence of the 1-year periodicity of activity in SS433. Nandi et al. [25] discussed the periodicity of flaring events in ASM RXTE X-ray data, and found possible period about 368 days.

## Conclusions

The RATAN microquasar monitoring data give us abundant material for comparison with X-ray data from the ASM or ToO programs with RXTE, CHANDRA, Suzaku and INTEGRAL. The 1-30 GHz emission originates often from different optically thin and thick regions and we proposed an adequate model of the flaring radio emission producing in the relativistic jets interacting with varying circumstellar medium or intense stellar wind.

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## REFERENCES

1. I. S. Shklovskii, *AZh* **37**, 1960, p.256
2. H. van der Laan, *Nature*, **211**, 1966, p. 1131
3. A. P. Marscher, W.K.Gear, *ApJ* **298**, 1985, p. 114.
4. M. J. Rees, *MNRAS* **184**, 1978, p. 61P
5. A. Levine, H. Bradt, W. Cui, et al., *ApJ* **469**, 1996, p. L33
6. S. D. Barthelmy, L. M. Barbier, J. R. Cummings, E. E. Fenimore, et al. *Space Science Reviews*, **120**, 2005, pp.143-164
7. S. A. Trushkin, N. N., Bursov, N. A. Nizhelskij, E. K. Majorova, P. A. Voitsik, *Proceedings of the VI microquasars workshop: Microquasars and Beyond*, 2006, p.15.1
8. A. J. Castro-Tirado, S. Brandt, N. Lund, *IAUC*, 1992, #5590
9. I. F. Mirabel, & L.F. Rodriguez, *Nature* **371**, 1994, p.46
10. R. P. Fender, D. Rayner, S. A. Trushkin, K. O'Brein, R. J. Sault, G. G. Pooley, R. P. Norris, *MNRAS* **330**, 2002, p.212
11. M. Namiki, S. A. Trushkin, T. Kotani, N. Kawai, N. N. Bursov, S.N. Fabrika, *Proceedings of the VI microquasars workshop: Microquasars and Beyond*, 2006, p.83.1
12. J. C. A. Miller-Jones, M. P. Rupen, S. Trushkin, G. G. Pooley, R. Fender, *ATel* #758, 2006, p.1
13. E. B. Waltman, R. L. Fiedler, K. L. Johnston, F.D. Ghigo, *AJ* **108**, 1994, p. 179
14. M. Tsuboi, N. Kuno, T. Umemoto, T. Sawada, et al., *ATel* #727, 2006, p.1
15. S. Pal, C. H. Ishwara-Chandra, A. Pramesh, *ATel* #809, 2006, p.1
16. S. A. Trushkin, G. Pooley, M. A. Harinov, A.G. Mikhailov, *ATel* #828, 2006, p.1
17. J. Marti, J. M. Paredes, R. Estalella, *A&A* **258**, 1992, p.309
18. R. M. Hjellming, *Galactic and extragalactic radio astronomy* (2nd edition) (A89-40409 17-90). Berlin and New York, Springer-Verlag, 1988, pp.381-438.
19. R. M. Hjellming, M. P. Rupen, R. W. Hunstead, et al., *ApJ* **544**, 2000, p.977
20. H. Watanabe, S. Kitamoto, S. Miyamoto, R. L. Fielder, E. B. Waltman, K. J. Johnston, F. D. Ghigo, *ApJ*, **597**, 2003, p.1023
21. R. L. Fiedler, K. J. Johnston, J. H. Spencer, E. B. Waltman et al. 1987 *AJ*, **94**, 1987, p. 1244
22. S. A. Trushkin, N. N. Bursov, N.A. Nizhelskij, *Bull. SAO RAS, Izvestij SAO* **56**, 2003, p.57
23. T. Kotani, S. A. Trushkin, R. K. Valiullin, S. Kinugasa, N. Safi-Harb, M. Kawai, M. Namiki, *ApJ* **637**, 2006, p.486
24. T. Kotani, et al., *Proc. of the VI microquasars workshop: Microquasars and Beyond*, 2006, p.50.1
25. A. Nandi, S. K. Chakrabarti, T. Belloni, P. Goldoni, 2005, *MNRAS*, **359**, p.629